DOCUMENT RESUME

ED 154 799 IR 005 892

AUTHOR Pratt, David
TITLE Cybernetic Principles in the Design of Instruction.
PUB DATE Mar 78
NOTE 22p.; Paper presented at the Annual Meeting of the American Educational Research Asscciation (Toronto, Canada, March 1978)

EDRS PRICE MF-$0.83 Plus Postage. HC Not Available from EDRS.
DESCRIPTORS Ability Grouping; Curriculum Design; *Cybernetics; Educational Development; Input Output Analysis; *Instructional Design; *Instructional Systems; Student Characteristics; *Systems Approach; Systems Building

ABSTRACT

Social, philosophical, and economic pressures are confronting curriculum designers with the major problem of designing instruction which produces consistently high learning despite wide variation in student characteristics. This is essentially a cybernetic question of regulating variety in a system to produce a stable output. It is observed that biological, contrived, and social systems all maintain a steady state by means of such devices as recognition of desired output, attenuation of input variety, sensing and signalling functions, and intervention mechanisms. Parallels to instruction suggest five basic propositions which relate to the design of instruction capable of producing consistently high learning output. (Author)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

ED154799

U S DEPARTMENT OF HEALTH,
EDUCATION & WELFARE
NATIONAL INSTITUTE OF
EDUCATION

THIS DOCUMENT HAS BEEN REPRODUCED EXACTLY AS RECEIVED FROM THE PERSON OR ORGANIZATION ORIGINATING IT. POINTS OF VIEW OR OPINIONS STATED DO NOT NECESSARILY REPRESENT OFFICIAL NATIONAL INSTITUTE OF EDUCATION POSITION OR POLICY

CYBERNETIC PRINCIPLES

in the

DESIGN OF INSTRUCTION

"PERMISSION TO REPRODUCE THIS MATERIAL IN MICROFICHE ONLY HAS BEEN GRANTED BY

David Pratt

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC) AND USERS OF THE ERIC SYSTEM."

Paper prepared for the Annual Meeting of the
American Educational Research Association
Toronto, March 1978

Session 6.09

David Pratt

Queen's University
Kingston, Canada

IR005 892

Cybernetic Principles in the Design of Instruction

Abstract

Social, philosophical, and economic pressures are confronting curriculum designers with the major problem of designing instruction which produces consistently high learning despite wide variation in student characteristics. This is essentially a cybernetic question of regulating variety in a system to produce a stable output. It is observed that biological, contrived, and social systems all maintain a steady state by means of such devices as recognition of desired output, attenuation of input variety, sensing and signalling functions, and intervention mechanisms. Parallels to instruction suggest five basic propositions which relate to the design of instruction capable of producing consistently high learning output.

CYBERNETIC PRINCIPLES IN THE DESIGN OF INSTRUCTION

Variability in student achievement

One of the central issues facing educators is, how can schools produce consistently high learning achievement, given variable student characteristics? It is the thesis of this paper that this is essentially a cybernetic question, and that the most efficient solution lies in the application of cybernetic principles to the design of instruction.

Traditionally, educators have accepted that differences in student characteristics will result in differences in achievement; indeed, that the process of schooling would amplify such differences, so that children apparently similar on entry to school would leave school at different stages with widely differing attainments and qualifications. Within a given program or classroom, it was expected that student achievement would vary from honors to failure, and organizational and evaluative practices were followed which promoted such variability. In cybernetic terms, schools were designed as unregulated, unstable, or open-loop systems, in which input variety was reflected by variety in output.

Conventional assumptions that diverse learner characteristics must lead to divergent achievement have in the past decade been challenged on the political, philosophical, and empirical fronts. The escalating cost of education has prompted public and politicians to ask why the products of the now almost universal twelve years of schooling should range from the highly qualified to the illiterate. Such philosophers as Rawls (1971) have questioned the liberal ideal of equality of opportunity, which, they argue, merely allows the fortunate or privileged "an equal chance to leave the less fortunate behind in the personal quest for influence or social position" (Porter, 1975(a), 17). Equality of outcome is proposed as a more valid goal. Finally, Bloom (1976), Keller (Keller and Sherman, 1974), and other learning psychologists have demonstrated that learning situations can be structured in such a way as to produce consistently high achievement from students who vary in their initial characteristics.

The kind of instructional system which is now being advocated by sections of both public and professional opinion is one which produces stable output from variable input. Expressed in these terms, the issue lies squarely in the field of cybernetics, the study of self-regulation in systems.

Cybernetics

The basic cybernetic paradigm can be represented in a block diagram as in Figure 1. This model is expanded in Figure 2.

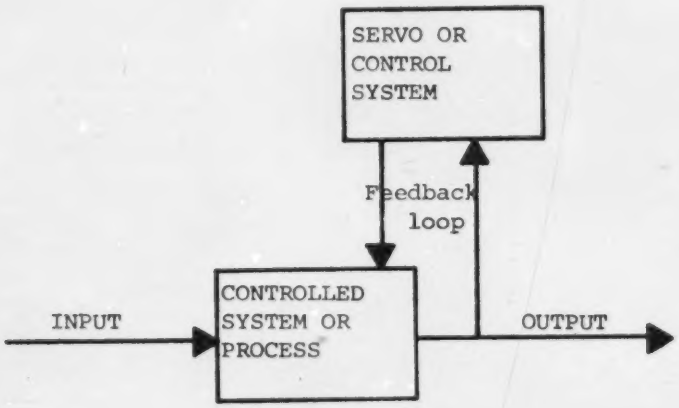

Figure 1

Basic Model of a Cybernetic System

Thermoregulation in a building will serve as a simple illustration of a cybernetic system. The input is the environmental temperature--a combination of air temperature, radiation, and wind speed. The effect of variation in external temperature is limited by the structure enclosing the building and its insulative qualities. The output of the system is the air temperature within the building, and this is monitored continuously by a sensor, usually a coiled bimetallic strip within the thermostat. The state of the system is compared with the set point, which in this case is the temperature setting. When the difference between the actual state and the set point reaches a critical level, an error signal activates

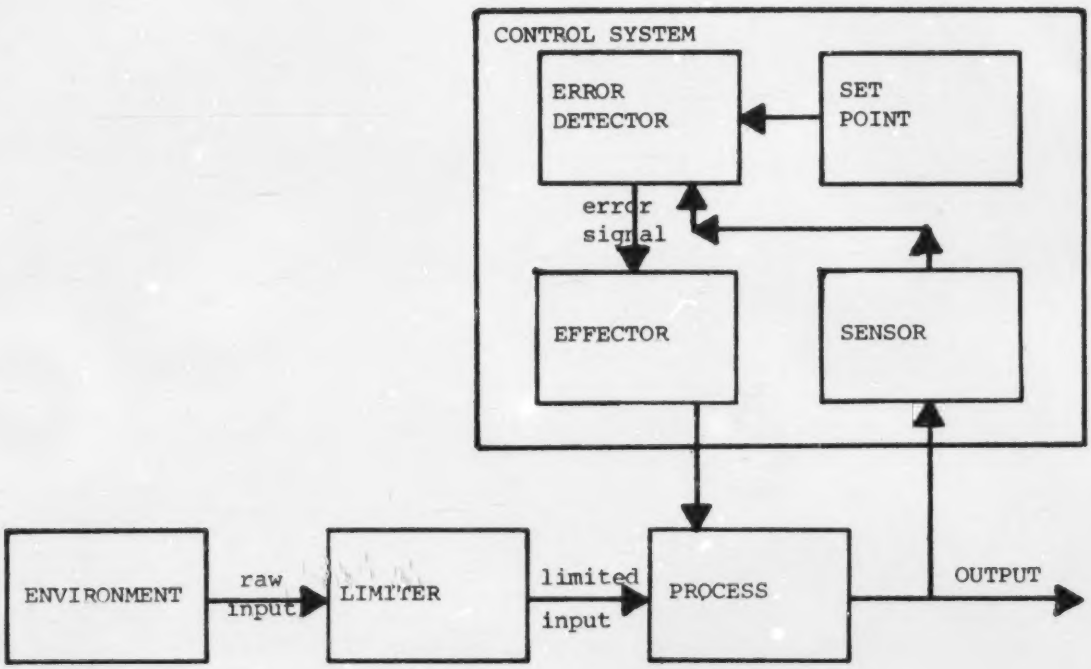

Figure 2

Expanded model of a cybernetic system

an effector. In a thermostat, the error signal is usually generated by an on/off mercury switch. The effector is the heating unit, which, once switched on, operates until the temperature reaches an upper threshold. Over time the system output, the internal building temperature, shows a low-amplitude symmetrical oscillation characteristic of a stable system (Figure 3).

A thermostat maintains a stable heat by using feedback, in Wiener's definition "a method of controlling a system by reinserting into it the results of its past performance" (1954, p. 61). The artifical heart pacemaker illustrates the difference between feedback, or closed-loop, and open-loop devices. The conventional pacemaker stimulates the heart-beat electrically at an unvarying rate. What happens, then, to the host who exerts himself--by running for a bus, for instance? It is quite likely that he will black out when the heart fails to provide sufficient oxygen. Pacemakers are now being developed which monitor rate of respiration

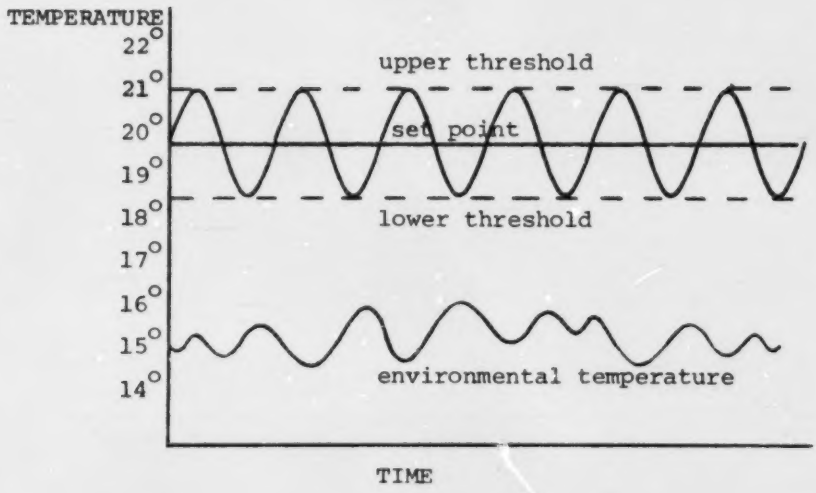

Figure 3

Domestic Thermoregulation

and respond by altering the rate of the electrical stimulus. Like the healthy heart, the new pacemakers are closed-loop feedback devices which can properly be termed cybernetic.

The first invention using cybernetic principles was probably a thermostat designed by Cornelius Drebbel (1572-1634) to regulate the temperature in a chicken incubator. Eighteenth-century windmills incorporated fantails which kept the structure turned towards the wind, and feathering mechanisms which adjusted the inclination of shutters in the sails to achieve automatic control of speed. Several efforts were made to regulate the speed of steam engines before Watt perfected his governor in 1769 (Figure 4). All of these inventions operated by feeding the error in the system (the difference between actual and desired output) back into the system and hence are feedback or closed-loop control systems.

The technological application of cybernetics preceded by many decades a theoretical understanding ofthe principles. The first theoretical explanation of the operation of feedback devices was produced by Maxwell in a paper "On governors" delivered to the Royal Society in 1867 (Rubin, 1968, p. 13). As the theoretical understanding increased, it became possible to use feedback principles in more sophisticated ways. In the

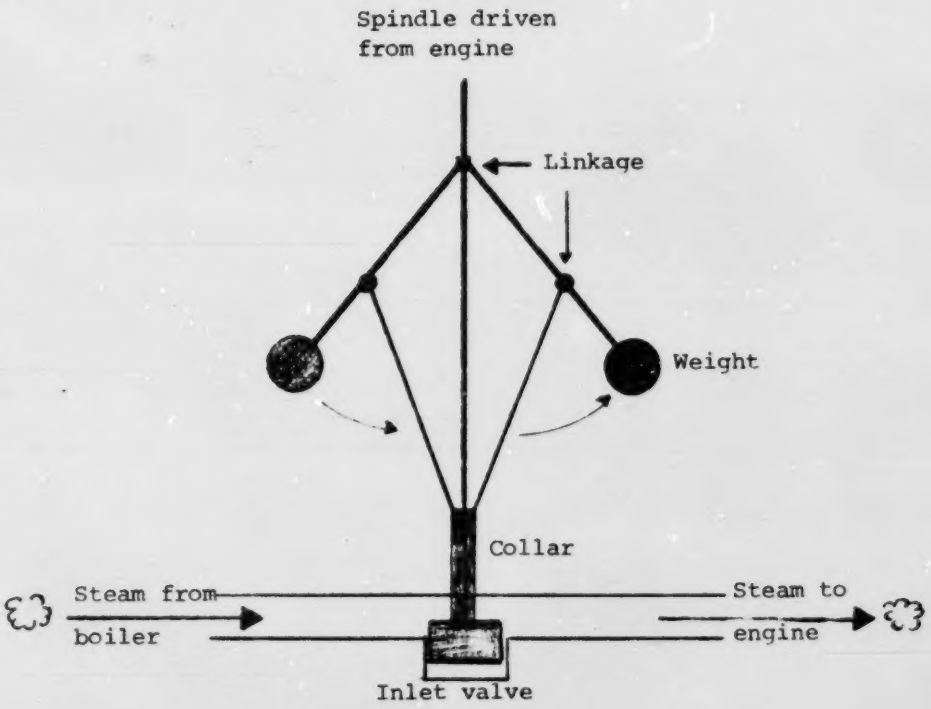

Figure 4

Watt's Steam Governor

As steam pressure increases or load decreases, the engine speeds up; increased centrifugal force pushes the flyballs outwards. This raises the arms connected to the inlet valve, reducing the amount of steam admitted. As speed decreases, the inlet valve is opened to restore equilibrium.

early twentieth century major advances began to be made in use of feedback in weaponry and in electronics.

Late in the nineteenth century, scientists began to take an increased interest in the self-regulation apparent in biological systems. By 1939 the process by which organisms achieve homeostasis had been extensively described. It was at about this time that Bertalanffy and others began to incorporate the principles of cybernetics into General System Theory (1968). The principles of self-regulation were an important part of an understanding of the process by which organic systems achieved growth and organization in apparent defiance of the Second Law of Thermodynamics (Bertalanffy 1970, p. 71).

The term cybernetics was not coined until the 1950s by Wiener (1954), the brilliant mathematician who had worked extensively on control systems in weaponry in World War II. Principles from information theory, developed during the same period, notably by Shannon (Shannon and Weaver 1949) made it possible to view cybernetics as a type of information-processing which could be described in mathematical terms.

In the past twenty years, the application of cybernetic principles has extended beyond technical inventions and the study of homeostasis to almost every field of science. Control mechanisms have been analyzed in social, economic, abstract, and organizational systems. Among the disciplines to which cybernetic theory has been applied are biology, business, demography, economics, geography, mathematics, philosophy, political science, psychology, psychiatry, and sociology. In all of these areas, the cybernetic model has been found to apply not simply as an analogy or metaphor, but in terms of principles which appear to operate with universal consistency.

A physiological system

Before examining the application of cybernetics to instruction, it may be valuable to complement the earlier examples of man-made feedback devices with an example of a natural system from the area of biocybernetics. The human body contains numerous cybernetic systems, remarkable for their elegance and precision, which maintain the various body functions and constituents in equilibrium. Temperature regulation is one such system. While it is extraordinarily elaborate and complex, its basic functioning is fairly well understood.

Man, like all animals, recognizes a comfortable environmental temperature, and seeks to limit the variety in temperature input by avoiding extremes of heat and cold. The simplest response to temperature change is behavioral: changing body location or position relative to sources of heat or cold; physical movement; and use of all the artifacts of buildings, clothing, and heating and cooling devices. Unlike most reptiles, which must rely exclusively on behavioral regulation of body temperature, man is equipped with an automatic regulative system, which, within an environmental temperature range of about 5° to 50°* provides an equilibrium finer than

* All temperatures are shown in Celsius.

behavioral responses can achieve (Cabanac 1972).

The human body has various temperature sensors which are unevenly distributed in the skin and in such parts of the core as the spinal cord and the walls of the intestine. Information regarding heat and cold is transmitted to the hypothalamus, a structure at the base of the brain, which is the main regulator of temperature as well as of many other body functions. The hypothalamus responds to neural feedback from the skin and other sensors; but it is itself sensitive to temperature, and it seems that its primary response is to the temperature of the blood flowing through the brain (Butter 1968).

The hypothalamus functions as the switching mechanism to initiate certain reactions to temperature change. There are essentially two distinct systems controlling temperature, one for heating and one for cooling. The former is regulated by the posterior hypothalamus, the latter by the anterior hypothalamus. The systems are to some extent independent, so that one part of the body can be warmed while another part is cooled. When body heat drops below a threshold level, a number of mechanisms come into operation. Increased adrenalin is secreted into the bloodstream, metabolic activity is accelerated, heart rate and blood pressure are increased, and peripheral blood vessels are constricted. If these responses are insufficient, the skin papillae are erected (gooseflesh), and delay in feedback from the brain to the small muscles produces the symmetrical oscillation we know as shivering (Cabanac 1975).

The cooling system reverses some of these processes. The thyroid gland becomes less active, heart rate and blood pressure are decreased, blood vessels in the limbs and body surface dilate. If these defenses do not restore equilibrium, sweat is secreted. The sodium chloride in sweat helps it to spread over the body surface; as it evaporates it cools the skin; as the skin dries, further sweat is produced until temperature is lowered. All the defenses come into play before blood temperature rises more than one degree. Above that level, the system is in danger of instability and collapse (Kerslake and Brebner, 1970).

Figure 5 shows the essential structure of the system, but it is a highly simplified model. There are in fact multiple feedback loops within the system. The caliber of the blood vessels, for instance,

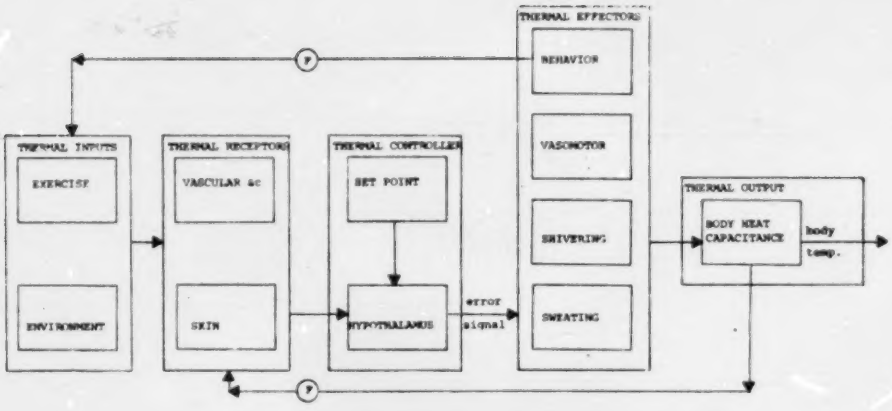

Figure 5

Simplified block diagram of human temperature regulation

can respond directly to cold, without the mediation of the hypothalamus (Keatinge 1970). Shivering appears to be a specific response to cooling of part of the spinal cord (Brück and Wünnenberg 1970). The nature of the set point is controversial, and it is not known whether the controlled variable is average body temperature, brain temperature, or some other factor (Mitchell, Atkins, and Wyndham 1972). Furthermore, the set point, unlike that in mechanical systems, itself varies. Temperature set point appears to be set at a higher level in fever (Cooper 1972), and normal body temperature varies slightly on a 24-hour rhythm (Aschoff 1970) and (in women) on a 28-day cycle. The set point also differs from one part of the body to another. Stolwijk (1970) identified equilibrium for brain temperature as 37.06°, for central blood temperature as 36.97°, and the weighted average for the skin as 34.81°.

The effectiveness of the temperature regulation system varies with such factors as cardiovascular fitness, body weight, and acclimatization. Experiments show that fit and acclimatized subjects can rest in an environmental temperature of 5° and perform heavy exercise, in which body heat product may reach 15 times the resting value, in environments up to 50° without losing equilibrium of body temperature (Nielsen 1970).

Cybernetic principles

A number of features are common to all cybernetic systems. Each of these aspects constitutes part of the regulatory process and contributes to the stability of the system. Scores of such characteristics have been identified and discussed in the literature (Miller 1965 a, b, c). Here only a few of the major features will be treated.

Characteristic 1 Cybernetic systems are teleological. All such systems have (or behave as if they have) a set point, representing a goal or optimal state which they generate themselves (teleogenic systems) or are designed to follow (teleonomic systems) (Locker and Coulter 1975). Without a set point, a system could not recognize the steady state, and hence could not achieve it (Beer 1974, p.12). In the natural state, most animal populations have a set point in terms of population relative to territory and availability of food, and are subject to various mechanisms, many of them extremely subtle, which maintain the population at a stable level (Slobodkin 1968). The set point is not always invariable. It may, as in the case of human body temperature, vary slightly but predictably. A system will adapt to persisting change in the environment by making a shift in the set point (Le Chatelier's Principle).
Principle 1 The more explicit the set point and the more clearly it is recognized by the system, the more stable the system.

Characteristic 2 The complexity of a system's control mechanism is proportionate to the variety of the system input (Ashby's Law) (Ashby 1956). Less complexity is necessary within a system if some variety is prevented from entering the system. Variety (in information terms, uncertainty) is simply the possible number of states of a system (Beer 1975). All systems have boundaries or strategies for preventing, avoiding, or reducing input variety. Animals minimize the effects of climatic change by migration, hibernation, construction of dens or nests, and by their hide, feathers, fur, or body fat. Contraction of the pupil of the eye is part of an "anticipatory feedback mechanism" which prevents the amount of light striking the retina from exceeding a danger limit. Churches, social clubs, and political parties allow membership only to those who subscribe to a certain doctrine or ethos. Such boundaries limit the variety which the internal regulative system must manage.

Principle 2 The more variety excluded from the system, the more stable the system.

Characteristic 3 All cybernetic systems have sensors which monitor the performance of the system. Sensors may operate continuously or intermittently. A car driver glances at his speedometer intermittently and accelerates or slows down to maintain a constant speed. The more frequently he checks the speedometer, the less correction will be necessary and the less the fluctuation in speed. On the other hand, he monitors direction continuously, again making intermittent corrections as the car moves too close to the center or edge of the road. The experienced driver also monitors his performance by means of auditory and kinesthetic receptors. The increased instability of the system which accompanies intoxication may be seen as the result of a slowing down and degradation of the feedback from these sensors (Drew, Colquhoun, and Long 1958). It has been shown that such motor skills as walking (Pearson 1976), or eye-head movement (Morasco 1975) are made possible by complex feedback systems with receptors in the muscles, joints, tendons, and skin which constantly monitor and compute changes in load, mechanical advantage, position, and rates of angular movement (Gibbs 1970). Tabes, a neurological disorder in which nerves carrying proprioceptive impulses from the legs suffer degeneration, interrupts the feedback loop. The sufferer must rely on visual and auditory feedback, hence the typical stamping gait of the tabes patient. If he is asked to stand with his eyes shut, he will fall over (Stanley-Jones 1970, p.6).

Principle 3 The more sensitive the sensors and the more frequently they operate, the more stable the system.

Characteristic 4 Signals from the sensors are transmitted to a controller which compares their value with a set point. If there is a critical difference, that is, if the value is above or below the predetermined thresholds, the controller signals remedial action. The faster the controller responds, the less likely it is that the fluctuation will disrupt the system. In a military campaign, a general behind the lines (the controller) compares information received from reconnaissance units (sensors) with his strategic objectives (set point), identifies the problem or discrepancy (system error), and orders action on the part of infantry, artillery, etc.

(effectors) which will bring him closer to the achievement of his objectives. An indecisive general increases the delay between determining the problem and ordering the appropriate response. A similar slowdown in response will occur if the decision must be approved by a group of commanders. In warfare (unlike chess), a good decision which is delayed may be less effective than an inferior decision which is implemented quickly. Hence MacAulay's observation that "Many an army has prospered under a bad commander, but no army has ever prospered under a debating society."

Principle 4 The more rapid the response of the controller, the more stable the system.

Characteristic 5 The controller ascertains error and acts as a switching mechanism for the effectors or actuators, which function to restore equilibrium. Equilibrium is of vital importance in a nuclear reactor. When a nucleus of uranium fuel splits, it releases on the average 2.5 neutrons. To prevent the chain reaction from proceeding exponentially, the surviving neutrons must be reduced to a factor of one. This is achieved by the insertion of rods of some such neutron-absorbing material as boron into the reactor core. The boron rods and the driving mechanism which automatically pushes them in and out of the core constitute the control system which sustains the nuclear chain reaction in a steady state (McIntyre 1975). In the human body, the controller of the temperature regulation system is the hypothalamus; the effectors are the thyroid, adrenal, and sweat glands, the heart, the vasodilator and vasoconstrictor centres, the arrector pili muscles, and the small muscles involved in shivering. The actuators "close the loop" in a feedback system; any reduction in their speed or effectiveness increases the fluctuation in the system.

Principle 5 The more rapid and effective the action of the effectors, the more stable the system.

Application to instruction

The ideal instructional system will be one which produces stable intended output; that is, one in which the achievement of all learners is consistently within certain limits. Cybernetic principles apply to the management of achievement at both upper and lower thresholds, but

this discussion will be limited to the issues involved in maintaining student achievement above a minimum level. Each of the five principles described above can be applied directly to the design of instruction.

1. Set point The set point is the goal for a system. All systems are goal-directed; only man is purposive, in the sense of being conscious of the goals he pursues (Kaplan 1964). Extensive research conducted over the past decade into the effect of specific goals on human performance supports Hamner's conclusion that "the most immediate, direct, and motivational determinant of task performance is the subject's goal" (1974, 217). Aims, objectives, and performance criteria constitute the set point for an instructional system. They will contribute to system stability to the extent that they are the focus of instruction, are explicit, and are accepted by all participants. At the micro level of instructional design, this position is widely accepted by the various schools of educational thought (Pratt, 1976), although its translation into practice is far from universal. What is still largely neglected in terms of policy is the set point at the macro level: the goals of public schooling and university education. This fosters suboptimization, a situation in which stable subsystems compete for resources within a system which lacks coherence or stability as a whole.

Proposition 1 The stability of an instructional system will be a function of the extent to which the intended outcomes of instruction are understood and accepted by the participants.

2. Exclusion of variety Systems deal with variety either by excluding it or by controlling it. The less variety is excluded, the more perturbation enters the system, and the greater the effort required to maintain stability. Conventional instructional situations exclude certain kinds of variety. In elementary and secondary school classrooms variety in pupil age is fairly strictly excluded. Most streaming or tracking procedures purportedly aimed at "ability grouping" in fact appear to exclude variety primarily in social class (Barker Lunn 1970, Husen and Svensson 1960, Schafer and Olexa 1971, Porter 1975(b)). Yet while variety in age and social class is restricted, high variety in cognitive background and motivation is permitted to enter the system. Particularly significant is the wide range in reading levels in any given classroom (Bond and

Tinker 1973, p. 51), which virtually guarantees variable achievement and learning speed in any academic area.

In cybernetic terms, what is happening in many schools is that certain basic systems, such as that designed to develop reading skills, are unstable. The high-variety output of these systems becomes the unregulated input to subsequent systems, which are not themselves designed to handle a high degree of fluctuation. Instead of negative feedback loops, which correct minor fluctuation as it occurs, positive feedback loops are established of underachievement--lowered motivation--lack of cognitive base for subsequent learning--increased underachievement. This general description is supported by recent research. In particular, Bloom (1976) and Anderson (1976) have shown that variation in learning speed and achievement can be reduced very significantly if students are equipped with the relevant cognitive prerequisites and prior experience of success in the subject.

Prerequisites have generally been discussed within an ideological frame of reference, in terms of the politics of inclusion and exclusion. From a cybernetic viewpoint, a prerequisite is valid if it contributes to the stability of the instructional system. This implies exclusion or dissuasion of students from instructional units in which their failure is predictable. Such exclusion, if temporary and without prejudice, and if reversible by remediation which is provided to make good the missing prerequisites, appears to conform to humane as well as to cybernetic principles.

Proposition 2 Application of relevant prerequisites will increase the stability of an instructional system.

3. Monitoring output The process of sensing output, comparing output with the set point, and signalling the error to an effector are combined in instruction in the process of formative evaluation. Strictly speaking, measurement is the sensor and evaluation is the comparator.

Classroom teachers monitor the achievement and motivation of individual learners with fairly high frequency, by observation of student verbal and nonverbal responses, overview of written work, and dialogue and consultation with individuals. Formative evaluation generally refers to a more or less formal procedure for measuring student achievement and

comparing it with output specifications. Ideally, formative evaluation is diagnostic, able to identify specific areas of weakness.

One of the keys to a stable instructional system is frequent monitoring: minor learning problems need to be identified before they produce major failure. Computer-based and computer-managed instruction can provide high-frequency monitoring. So can electronic feedback devices designed for classroom installation, or simply a prearranged code of hand-signals. But in many classrooms formal monitoring on a daily basis would absorb a disproportionate amount of time. The system would be overdamped: the cost of stability would be slow progress toward the goal. On the other hand, assessing achievement only once or twice a semester could allow the achievement of individual learners to get out of control. A consensus appears to be emerging among proponents of mastery learning that the optimal size for an instructional unit is about three weeks, ten hours of instruction, or as much material as can be adequately tested in twenty minutes (Bloom 1976, p. 22; Keller and Sherman 1974, p. 27).

Proposition 3 The stability of an instructional system will be a function of the sensitivity and frequency of formative evaluation.

4. Remediation Remediation is the effector used with learners whose achievement falls below a predetermined threshold. If remediation is to restore stability to the instructional system, it must be sufficiently effective that it restores the underachieving student to the mainstream of the class, and it must be rapid enough that it has this effect before the other students have forged much further ahead. Reliance on individual tuition by the teacher, or on vague instructions to underachieving learners to review past work are likely to be both slow and ineffective. Prerecorded audio cassettes, structured peer tutoring, random-access audiovisual materials, or print materials brief, specific, and motivational enough to be used in the pupil's own time are more likely to be appropriate. Such approaches imply prior design of remedial units: remediation can be designed after underachievement is detected only at the risk of instability. All of this assumes that underachievement will occur in a small minority of students. Significant underachievement on the part of large numbers of students in a class suggests design defects which remedial procedures alone may be unable to overcome.

Proposition 4 An instructional system will be stable to the extent that remedial procedures are rapid and effective.

5. The learner as a cybernetic system The discussion thus far has viewed the classroom as the instructional system, with the instructor performing the controller functions. The stability of the system will be increased if each student also acts as his own controller. This can occur only if the learner recognizes and accepts the set point of the system. Not only must he know what are the expected learning outcomes and how they can be assessed, he must acknowledge their value if he is to be motivated to guide and adjust his own learning. Porter likens motivation in learning to the gain in a feedback loop. "Successful moves which give rise to the reduction of error are more strongly reinforced the higher the gain in the system" (1969, p. 135). This seems to be one of many reasons for basing curriculum objectives on real and significant student needs, and making the effort to persuade learners of the value of objectives when this is not self-evident. Hence, while the emphasis on objectives which has been characteristic of curriculum thought in the past two decades is salutary, its impact is limited unless the selection of objectives is based on a sound and rigorous process of needs assessment.

Proposition 5 An instructional system will be stable to the extent that the individual learner recognizes and is motivated by the intended outcomes of instruction, and can monitor and correct his own learning.

The function of cybernetic theory in instruction

The function of a theory is to explain and predict events and phenomena. Apart from what it owes to learning theory, instructional design has generally developed on the pragmatic basis of what appears to be effective. Much of the instructional design literature is characterized by an engaging sense of surprise that certain strategies work so well. Cybernetics furnishes a theoretical rationale for the procedures which many educators have developed by trial and error or intuition. The relatively recent approaches of Mastery Learning, Personalized System of Instruction, and Competency-Based Instruction exemplify the principles of clear objectives and prerequisites, and frequent monitoring and remediation. So do the age-old practices used by a master potter training an apprentice, a

Buddhist monk instructing a disciple, and a mother teaching a nursery rhyme to a child.

Daniel Benor, the Israeli agricultural expert who has had great success in teaching third world farmers how to produce more food, commented recently that "there are almost no new ideas, merely well-known principles applied systematically" (Rowen 1978). This appears to be the case with instructional design. And just as the world can no longer afford inefficient agriculture, society's tolerance is diminishing for schooling systems which operate at an amateur level of efficiency. By providing a theoretical explanation for certain fundamental and familiar instructional practices, cybernetics enhances our ability to design instructional systems whose effectiveness is predictable.

References

Anderson, Lorin W. An empirical investigation of individual differences in time to learn. Journal of Educational Psychology 1976, 68, 226-233.

Aschoff, Jürgen. Circadian rhythm of activity and of body temperature. In James D. Hardy, A. Pharo Gagge and Jan A. J. Stolwijk (Eds.) Physiological and behavioral temperature regulation. Springfield, Ill.: Charles C. Thomas, 1970, pp. 905-919.

Ashby, W. R. Introduction to cybernetics. New York: Wiley, 1956.

Barker Lunn, Joan C. Streaming in the primary school. Slough, England: National Foundation for Educational Research, 1970.

Beer, Stafford. Designing freedom. Toronto: CBC Publications, 1974.

Beer, Stafford. On heaping our science together. In Robert Trappl and Franz R. Pichler (Eds.) Progress in cybernetics and systems research. Vol. 1. Washington: Hemisphere, 1975, pp. 3-11.

Bertalanffy, Ludwig von. General system theory. New York: Brazillier, 1968.

Bertalanffy, Ludwig von. Chance or law. In Arthur Koestler and J. R. Smithies (Eds.) Beyond reductionism: New perspectives in the life sciences. New York: MacMillan, 1970, pp. 56-76.

Bloom, Benjamin S. Human characteristics and school learning. New York: McGraw Hill, 1976.

Bond, Guy L. and Miles A. Tinker. Reading difficulties: Their diagnosis and correction. Englewood Cliffs, N.J.: Prentice-Hall, 3rd. ed., 1973.

Brück, Kurt, and Wolf Wünnenberg. "Meshed" control of two effector systems: Nonshivering and shivering thermogenesis. In James D. Hardy, A. Pharo Gagge, and Jan A. J. Stolwijk (Eds.) Physiological and behavioral temperature regulation. Springfield, Ill.: Charles C. Thomas, 1970, pp. 562-580.

Butter, Charles M. Neuropsychology: The study of brain and behavior. Belmont, Cal.: Wadsworth, 1968.

Cabanac, Michel. Thermoregulatory behavior. In J. Bligh and R. E. Moore (Eds.) Essays on temperature regulation. Amsterdam: North-Holland 1972, pp. 19-36.

Cabanac, Michel. Temperature regulation. Annual Review of Physiology, 1975, 37, 415-439.

Cooper, K. E. The body temperature "set-point" in fever. In J. Bligh and R. E. Moore (Eds.), Essays on temperature regulation. Amsterdam: North-Holland, 1972, pp. 149-162.

Drew, G. C., W. P. Colquhoun, and H. A. Long. Effect of small doses of alcohol on a skill resembling driving. British Medical Journal, 1958, 5103, 993-999.

Gibbs, C. B. Servo-control systems in organisms and the transfer of skill, In David Legge (Ed.) Skills. Harmondsworth, England: Penguin, 1970, pp. 211-226.

Hamner, W. Clay. Goal setting, performance and satisfaction in an interdependent task. Organizational behavior and human performance, 1974, 12, 217-230.

Husen, Torsten, and Nils-Eric Svensson. Pedagogic milieu and development of intellectual skills. School Review, 1960, 68, 36-51.

Kaplan, Abraham. The conduct of inquiry. San Francisco: Chandler, 1964.

Keatinge, William R. Direct effects of temperature on blood vessels: Their role in cold vasodilation. In James D. Hardy, A. Pharo Gagge, and Jan A. J. Stolwijk (Eds.) Physiological and behavioral temperature regulation. Springfield, Ill.: Charles C. Thomas, 1970, pp. 231-236.

Keller, Fred S. and J. Gilmour Sherman. The Keller Plan handbook. Menlo Park, Cal.: W. A. Benjamin, 1974.

Kerslake, David McK., and Derek F. Brebner. Maximum sweating at rest. In James D. Hardy, A. Pharo Gagge, and Jan A. J. Stolwijk (Eds.) Physiological and behavioral temperature regulation. Springfield, Ill.: Charles C. Thomas, 1970, pp. 139-151.

Locker, A., and N. A. Coulter. An outline of teleogenic systems theory. In Robert Trappl and F. de P. Hanika. Progress in cybernetics and systems research, Vol.2. Washington: Hemisphere, 1975, pp. 156-165.

McIntyre, Hugh C. Natural uranium heavy-water reactors. Scientific American, 1975, 233 (Oct.), 17-27.

Miller, James G. Living systems: Basic concepts. Behavioral Science, 1965, 10, 193-237 (a).

Miller, James G. Living systems: Structure and process. Behavioral Science, 1965, 10, 337-379 (b).

Miller, James G. Living systems: Cross-level hypotheses. Behavioral Science, 1965, 10, 380-411 (c).

Mitchell, Duncan, A. R. Atkins, and C. H. Wyndham. Mathematical and physical models of thermoregulation. In J. Bligh and R. E. Moore (Eds.), Essays on temperature regulation. Amsterdam: North-Holland, 1972, pp. 37-54.

Morasso, Pietro and Vincenzo Tagliasco. Results and perspectives of the study of eye-head motor coordination. In Robert Trappl and Franz R. Pichler (Eds.), Progress in cybernetics and systems research, Vol. 1. Washington: Hemisphere, 1975, pp. 334-341.

Nielsen, Marius. Heat production and body temperature during rest and work. In James D. Hardy, A. Pharo Gagge, and Jan A. J. Stolwijk (Eds.), Physiological and behavioral temperature regulation. Springfield, Ill.: Charles C. Thomas, 1970, pp. 205-214.

Pearson, Keir. The control of walking. Scientific American, 1976, 235 (Dec.), 72-86.

Porter, Arthur. Cybernetics simplified. London: English Universities Press, 1969.

Porter, John. Education and equality (1). Integrated Education, 1975, 13 (76), 17-20 (a).

Porter, John. Education and equality (2). Integrated Education, 1975, 13 (77), 41-43 (b).

Pratt, David. Humanistic goals and behavioral objectives: Towards a synthesis. Journal of Curriculum Studies, 1976, 8 (1), 15-26.

Rawls, John. A theory of justice. Cambridge, Mass.: Harvard University Press, 1971.

Rowen, Hobart. Making more corn to grow. Washington Post article reprinted in Manchester Guardian Weekly, 8 January 1968, p. 16.

Rubin, M. D. History of technological feedback. In John H. Milsum (Ed.), Positive feedback. Oxford: Pergamon Press, 1968, pp. 9-22.

Schafer, Walter E. and Carol Olexa. Tracking and opportunity. Scranton, Pa.: Chandler, 1971.

Shannon, C. E. and W. Weaver. The mathematical theory of communication. Urbana, Ill.: University of Illinois Press, 1949.

Slobodkin, L. B. Animal populations and ecologies. In John H. Milsum (Ed.), Positive feedback. Oxford: Pergamon Press, 1968, pp. 149-163.

Stanley-Jones, D. Kybernetics of mind and brain. Springfield, Ill.: Charles C. Thomas, 1970.

Stolwijk, Jan A. J. Mathematical models of thermoregulation. In James D. Hardy, A. Pharo Gagge, and Jan A. J. Stolwijk (eds.), Physiological and behavioral temperature regulation. Springfield, Ill.: Charles C. Thomas, 1970, pp. 703-721.

Wiener, Norbert. The human use of human beings: Cybernetics and society. London: Eyre and Spottiswoode, 1954.